

## A REVIEW ON APPLICATIONS OF MULTI-CRITERIA DECISION

### MAKING (MCDM) FOR SOLAR PANEL SELECTION

SASIKUMAR GNANASEKARAN<sup>1</sup> & N. VENKATACHALAM<sup>2</sup>

<sup>1</sup>Professor and Head, Department of Power Engineering, GMR Institute of Technology,

Srikakulam, Andhra Pradesh, India

<sup>2</sup>Associate Professor, Department of Mechanical Engineering, Excel Engineering College,

Komarapalayam, Tamil Nadu, India

#### ABSTRACT

Solar energy is considered as the most used resources of non-conventional energy compared to Wind and Tidal energy. A photovoltaic (PV) system is used to generate solar energy by photovoltaics. The solar panel is one of the vital parts of a photovoltaic system and there has been a lot of research works reported with the objective of reducing its material costs with better energy efficiency. In order to select the best solar panel, it is necessary to make a balance between tangible and intangible criteria that conflict with each other. The various problems of solar panel selection and the existing methods to solve the problems have been studied elaborated in this research work. The findings of this review paper will help the stakeholders and decision makers in sorting out some of the uncertainties in the selection of Solar panel.

**KEYWORDS:** Solar Panel, Analytical Hierarchy Process, Fuzzy AHP, TOPSIS & VIKOR

**Received:** Dec 13, 2018; **Accepted:** Jan 03, 2019; **Published:** Feb 02, 2019; **Paper Id.:** IJMPERDAPR20192

#### INTRODUCTION

In recent years, Solar panels are used for less scale energy generation, particularly for commercial or residential use in complexes or individual buildings with efficiency ranges from 18%-12%. The solar panel is an important component of a photovoltaic system and there has been a lot of research works carried out globally in order to reduce its material costs while improving energy efficiency. There are two different crystal types used in solar panels such as polycrystalline and mono-crystalline (Hamilton J, 2011). Polycrystalline panels are usually less efficient due to the presence of only one crystal, but are cheaper while monocrystalline is a small piece more expensive, but generally more efficient (Jager W, 2006). The total cost of the solar panel depends on size (in W), the brand, the physical size, the longevity /durability and any certifications of the panel. Selection of solar panel for a PV system is a Multi-Criteria Decision Making (MCDM) problem involving both qualitative and quantitative parameters. MCDM is a complex decision making tool as it involves both quantitative and qualitative criteria. In recent years, several MCDM techniques and approaches have been suggested to solve energy planning problems. The purpose of this paper is to review the nature of MCDM techniques such as AHP, Fuzzy AHP and Grey Relational Analysis (GRA) and explore the possibility of applying these techniques for solar panel selection.

#### SELECTION CRITERIA FOR SOLAR PANEL

The selection of solar panel depends on the following criteria:

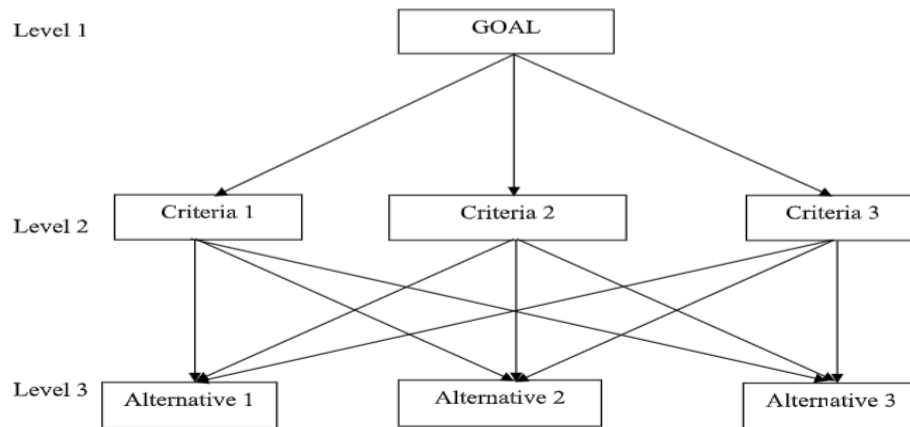
- **Electrical Properties:** Electrical properties of the are the Major Criteria which is determined by the following sub-Criteria:
  - **PTC Power Rating:** It is expressed in Watts. The peak power rating is the maximum output under standard test conditions and higher power rating is preferred.
  - **Temperature co-Efficient:** The temperature co-efficiency rating is important to determine what the impact heat has on a solar panel's operation after installation. The lower the percentage per degree Celsius, the better.
  - **Peak Efficiency:** with high peak efficiency is preferred.
  - **Energy Density:** It is expressed in amps and high value of power current is desirable.
  - **STC Power:** It is expressed in volts and high value of power current is desirable.
- **Weight:** with less weight is preferable.
- **Quality:** The quality of different solar panels.
- **Service support**

## AHP

The AHP is a Multiple Criteria Decision Making (MCDM) tool. This is an Eigen value approach to the pair-wise comparisons. It also provides a methodology to calibrate the numeric scale for the measurement of quantitative as well as qualitative performances. The scale ranges from 1/9 for 'least valued than', to 1 for 'equal', and to 9 for 'absolutely more important than' covering the entire spectrum of the comparison.

This method is created by Saaty (1980) in University of Pittsburgh. The AHP provides the relative ease but theoretically strong multi-criteria methodology for evaluating alternatives. It enables decision makers to use a simple hierarchy structure to deal with a complicated problem and to evaluate both quantitative and qualitative data in a systematic methodology under conflicting multi-criteria Lee et al (2001). The AHP lastly accomplishes an optimal alternative under the following four stages: decomposition, pair wise comparisons, priority vector generation and synthesis (Saaty, 1980; Kumar and Ganesh, 1996):

- State the problem.
- Broaden the objectives of the problem and its outcome.
- Identify the criteria that influence the objectives
- Break down the multi-criteria problem into a hierarchical structure with a number of small constituent elements, as shown in Figure 1
- A series of pair-wise comparisons are carried out among the elements at the same level in the next higher level using Saaty's nine-point scale.
- Generate the priority vector using the eigenvector method at each level with respect to every element.
- A final priority vector of alternatives is obtained by synthesizing all the priority vectors.



**Figure 1: Structure of Decision Hierarchy**

AHP can help the managers in the solar panel selection process in the following ways:

- Analysing the impact of sources on multiple goals of an organization.
- Facilitating the interactive flow of inputs from managers at all levels to evaluate the sources from a strategic perspective
- Facilitating the interactive flow of inputs from various organizational levels because the solar panel selection is frequently made after several cycles of trial and error. The AHP model can facilitate the process of reaching a satisfying decision by simulating various consequences.
- Allowing flexibility to the managers in different contexts, because material managers have to manage supply functions under increasing environmental uncertainty and rapid technological, economic and political changes in the international arena.

## **FUZZY AHP**

Although the AHP is used for MCDM problem widely, it is still often criticized by some scholars because of the following disadvantages (Cheng et al 1999a; Mikhailov 2003; Chan 2003):

- The AHP method is mainly used in nearly crisp decision applications.
- The AHP is the use of an unbalanced scale of estimations.
- The AHP does not take into account the uncertainty and risk in assessing the alternative's potential performance because it assumes the relative importance of criteria affecting alternative's performance is certain.
- The subjective judgment, selection and preference of decision makers result in large influence.

Therefore, the concept of fuzzy set theory is integrated with the AHP to overcome the above disadvantages. Fuzzy AHP and its extensions are developed to solve alternative selection and justification problems. Although fuzzy AHP requires tedious computations, it is capable of capturing a human's appraisal of ambiguity for solving complex MCDM problems. In the literature, many fuzzy AHP methods have been proposed. Saaty (1978) proposed a method to give meaning to both fuzziness in perception and fuzziness in meaning. Later on, Buckley (1985) extended Saaty's AHP method by incorporating decision maker's preference using fuzzy ratios instead of crisp values. Chang (1996) developed a

fuzzy extent analysis for AHP having similar steps as that of Saaty's crisp AHP. This approach is relatively easier in computation than the other fuzzy AHP approaches. Kahraman et al (2004) and, Kulak and Kahraman (2005) applied Chang's (1995) fuzzy extent analysis in the selection of the best catering firm, facility layout and the best transportation company, respectively. Kahraman et al (1998) used a fuzzy objective and subjective method obtaining the weights from AHP and made a fuzzy weighted evaluation. Deng (1999) presented a fuzzy approach for tackling qualitative multi-criteria analysis problems in a simple and straightforward manner. Lee et al (1999) reviewed the basic ideas behind the AHP. Based on these ideas, they introduced the concept of comparison interval and proposed a methodology based on stochastic optimization to achieve global consistency and to accommodate the fuzzy nature of the comparison process.

Cheng et al (1999) proposed a new method for evaluating weapon systems by AHP based on linguistic variable weight. Zhu et al (1999) made a discussion on extent analysis method and applications of fuzzy AHP. Chan et al (2000) presented a technology selection algorithm to quantify both tangible and intangible benefits in fuzzy environment. They described an application of the theory of fuzzy sets to hierarchical structural analysis and economic evaluations. Chan et al (2000) reported an integrated approach for the automatic design of FMS using simulation and multi-criteria decision-making techniques. Leung and Cao (2000) proposed a fuzzy consistency definition with consideration of a tolerance deviation. Essentially, the fuzzy ratios of relative importance, allowing certain tolerance deviation, are formulated as constraints on the membership values of the local priorities.

## GREY RELATIONAL ANALYSIS

Grey system theory originated with Deng (1982). A system having incomplete information is called Grey system. It can be used to solve ambiguous problems in cases with discrete data and incomplete information Deng (1989). Grey system is a theory and methodology that deals with incomplete or uncertain systematic problems. One of the major advantages of grey system theory is that it can generate satisfactory results using a relatively small amount of data. It achieves this by increasing the regularity of data with proper treatment Li et al (1997). Like fuzzy set theory, grey theory is thus an effective mathematical model for resolving uncertain and imprecise problems Hsu and Wen (2000).

Chin-Tasi Lin et al (2003) developed a model for selecting Internet advertising networks using an AHP and GRA. Lin and Yang (1999) used GRA to select home mortgage loans. Lin and Hsu (2001) used GRA to determine a shortlist of advertising agencies. GRA has been successfully applied to various decision problems – including performance evaluation of airlines (Feng and Wang, 2000), scheduling of hydroelectricity (Liang 1999), image compression (Hsu et al 2000), and multiple-attribute decision-making problems (Wu 2003; Chiou and Tzeng 2001).

## APPLICATIONS OF MCDM FOR ENERGY PROBLEMS

MadjidTavana et al. (2017) developed a fuzzy multi-criteria spatial decision support system for solar farm location planning. An ANFIS (Adaptive Neuro-Fuzzy Inference System) is implemented on the set of the grid intersection crisp data points and a coherent set of approximations per each potential discrete location derived. The fuzzy AHP (Analytic Hierarchy Process) method is used to determine the weights of the different criteria considered from the linguistic evaluations provided by different experts. Wang et al. (2009) presented a review on multi-criteria decision analysis in renewable energy decision making systems. Cai et al. (2009) proposed an optimization model which is an interactive decision support system for planning regional energy management systems.

Cai, Huang, and Yang (2009) developed an integrated stochastic and fuzzy environment system to manage renewable energy systems. Patlitzianas et al. (2008) offered an information decision support system to formulate modern energy companies' environment. Kowalski et al. (2009) proposed the hybrid use of scenario building and participatory multi-criteria analysis for renewable energy. Beltran P. (2013) developed an analytic network process (ANP) model to the selection of photovoltaic (PV) solar power projects. Kahraman et al. (2009) proposed a multi-attribute selection model of renewable energy alternatives with fuzzy axiomatic design and fuzzy analytic hierarchy process. Kaya et al. (2010) is proposed a multicriteria model to determine the best renewable energy alternative for İstanbul with an integrated VIKOR-AHP methodology. Önüt, Tuzkaya, and Saadet (2008) represented an ANP model to perform a multiple criteria evaluation on the most suitable energy resources for the Turkish manufacturing industry. Heo, Kim, and Boo (2010) performed an analysis of the evaluation factors for renewable energy program with fuzzy AHP.

Amin et al., (2009) developed a field study of various solar cells on their performance in Malaysia. AthakornKengpol et al., (2013) proposed a decision support system for avoiding flood on solar power plant site selection using the geographic information system (GIS) to determine the optimum site for a solar power plant. Liu and Hai (2005) stated that the strength of the AHP lies in its ability to structure a complex, multi-person and multi-attribute problem hierarchically, and then to investigate each level of the hierarchy separately, combining the results. Charabi and Gastli (2011) found the suitability of installing solar PV power plants in Oman by combining GIS and multi-criteria fuzzy methodology. Fuzzy replacement analysis and analytic hierarchy process in the selection of operating system was developed using economic and Non-economic factors (Tolga et al., 2005).

A. Mardani et al., (2017) conducted a critical review on the application and use of decision making approaches in regard to energy management problems. Sánchez-Lozano et al., (2014) developed Applied ELECTRE-TRI and GIS for selection of photovoltaic solar farm sites. Cavallaro (2010) developed the Fuzzy TOPSIS approach for evaluating thermal-energy storage in a concentrated solar power system. Ghazanfar Khan et al., (2014) developed a methodology to locate potential sites for large-scale Solar PV (SPV) plants focusing on various factors. Factors have classified as "analysis criteria" and "exclusion criteria". The criteria such as Availability of solar radiation, Availability of vacant land, Distance from highways and existing transmission lines etc. have considered as analysis criteria. Variations of local climate, module soiling, topography of site etc. are exclusion criteria.

S. A. Khaparde et al. (2008) listed feasible solutions associated with large scale deployment of the renewable energy technologies. Various alternatives presented here are likely to change the look of the future power system. R. Nagalakshmi et al (2014) implemented a Prototype solar PV monitoring and optimization includes a data acquisition system, Supervisory monitoring and control station at plant level and Decision Support System (DSS) at the Central Control Station. Tripathi et al. (2012) conducted a performance investigation for solar PV systems from mc-Si and a-Si grid-connected PV technologies in two 500 kW solar PV power plants located at the same place in Gujarat, Western India.

Sharma et al., (2013) explored the performance characteristics of a 190 kWp p-Si PV power plant in India and found that the maximum energy generated from the PV power plant is during March, September, and October and the minimum in January. AbhiravMathur et al., (2015) designed a photovoltaic array and defined inverter sizes for a grid-connected PV system. Various inputs like the load, peak power, module voltage, global irradiance and tilt angle are given and a detailed report on the losses of PV array as well as the inverter are obtained.

HimaniMaheshwari et al., (2017) in a case study on Financial Viability of Solar Photovoltaic System estimated the generated solar energy production and carbon credits earned by the photovoltaic cells of multi crystalline solar photovoltaic module. Also the analysis has been done for the amount of carbon footprint and payback period.

## CONCLUSIONS

In this section, the reasons for solar panel selection using integrated mathematical modelling techniques such as Fuzzy AHP and AHP & GRA are discussed. A critical review of the literature shows that there are a large number of decision making methods and tools available for solar panel selection. Due to the multi objective nature of the solar panel selection process, there is more work highlighting the use of quantitative models based decision making methods. These models focus less on addressing the issue of subjective (qualitative) criteria for solar panel selection. A decision model in accommodating both subjective and objective criteria with accurate and faster calculation procedure in making the solar panel selection simpler and user friendly is desirable. This warrants the development of a new decision support system in order to resolve MCDM to the solar panel selection problem.

Based on the literature review, the following makes the solar panel selection decision making process difficult and complicated:

- Multiple criteria – both qualitative and quantitative
- Conflicts amongst criteria – conflicting objectives of the criteria
- Involvement of many alternatives – due to stiff global business competition
- Internal and external constraints imposed on the buying process

### Reasons for Selecting Fuzzy AHP

The AHP method is mainly used in nearly crisp decision applications. The AHP does not take into account the uncertainty and risk in assessing the alternative's potential performance because it assumes the relative importance of criteria affecting alternative's performance is certain. The subjective judgment, selection and preference of decision makers result in large influence.

### Reasons for Selecting Integrated Solar Panel Selection Model Based on AHP and GRA

From the literature review on solar panel selection, it is found that LW models do not include quantitative factors (such as cost, distance and delivery time), whereas the MP models are limited as they do not consider qualitative factors (such as finance and customer service). Most of the researchers used an AHP method to deal with the solar panel selection problem, taking into account the qualitative criteria only in the solar panel evaluation. However, in the proposed integrated model based on AHP and GRA, both qualitative and quantitative criteria are considered simultaneously in the evaluation and selection of solar panels. The quantitative criteria (cost, peak efficiency, energy density and weight) have the characteristic of "smaller-is-better" and the "larger-is-better" for the qualitative criteria (service and quality).

**REFERENCES**

1. Amin, N., Lung, C. W., Sopian, K. (2009), 'A practical field study of various solar cells on their performance in Malaysia', *Renewable Energy Journal*, Vol. 34, No. 8, , pp.1939-1946.
2. Athakorn Kengpol, Piya Rontlaong, Markku Tuominen (2013), 'A Decision Support System for Selection of Solar Power Plant Locations by Applying Fuzzy AHP and TOPSIS: An Empirical Study', *Journal of Software Engineering and Applications*, 6, 470-481.
3. Buckley J.J. (1985), 'Fuzzy Hierarchy Analysis, Fuzzy Sets and Systems', Vol. 17, pp. 233-247.
4. Beltran P. (2013), 'An AHP (Analytic Hierarchy Process)/ANP (Analytic Network Process)-based multi-criteria decision approach for the selection of solar-thermal power plant investment projects', *Energy*, 17, 645-658.
5. Cai, Y. P., Huang, G. H., Lin, Q. G., Nie, X. H., Tan, Q. (2009), 'An optimization-model-based interactive decision support system for regional energy management systems planning under uncertainty', *Expert Systems with Applications*, Vol. 36, No. 2, 2009, pp.3470-3482.
6. Cavallaro F. (2010), 'Fuzzy TOPSIS approach for assessing thermal-energy storage in concentrated solar power (CSP) systems', *Applied Energy*, Vol. 87, pp.496-503.
7. Chang D.Y. (1996), 'Applications of the extent analysis method on fuzzy AHP', *European Journal of Operational Research*, Vol. 95, pp.649-55.
8. Chetan Solanki, "Solar Photovoltaics, Fundamentals, Technologies and Application" 3rd edition, PHI Learning Pvt Ltd, 2013.
9. Chiang K.S. (1997), 'The Introduction of Grey Theory', Gauji Publishing Co., Taipei.
10. Chin-Tasi Lin and Pi-Fang Hsu (2003), 'Selection of Internet Advertising Networks Using an Analytic Hierarchy Process and Grey Relational Analysis', *Information and Management Sciences*, Vol. 14, No. 2, pp.1-16.
11. Deng J.L. (1982), 'Control problems of grey system', *Systems and Control*, Vol. 1, pp. 288-94.
12. Deng J.L. (1989), 'Introduction to grey system theory', *The Journal of Grey System*, Vol. 1 No. 1, pp. 1-24.
13. Deng, H. (1999), 'Multi-criteria Analysis with Fuzzy Pairwise Comparison', *International Journal of Approximate Reasoning*, Vol.21, pp. 215-231.
14. HasanMahamudul, MekhilefSaad, and Metselaar Ibrahim Henk (2013), "Photovoltaic System Modelling with Fuzzy Logic Based Maximum Power Point Tracking Algorithm. "Hindawi Publishing Corporation, *International Journal of Photo energy*.
15. Heo, E., Kim, J., Boo, K. J. (2010), "Analysis of the assessment factors for renewable energy dissemination program evaluation using fuzzy AHP, *Renewable and Sustainable Energy Reviews*, 2010.
16. HimaniMaheshwari and Kamal Jain (2017), *International Journal of Civil Engineering and Technology (IJCIET)*, Volume 8, Issue 11, November 2017, pp. 180-190.
17. Hsu C.I. and Wen Y.H. (2000), 'Application of Grey Theory and Multiobjective Programming Towards Airline Network Design', *European Journal of Operational Research*, Vol. 127, pp.44-68.
18. Kahraman, C., Cebeci, U. and Ulukan, Z. (2003), 'Multi-criteria Supplier Selection Using Fuzzy AHP', *Logistics Information Management*, Vol. 16, pp. 382-394.
19. Kahraman, C., Kaya, İ., Cebi, S. (2009), 'A comparative analysis for multiattribute selection among renewable energy alternatives using fuzzy axiomatic design and fuzzy analytic hierarchy process, *Energy*, Vol. 34, No. 10, pp.1603-1616.



20. Kaya, T., Kahraman, C., A fuzzy multicriteria methodology for selection among energy alternatives, *Expert Systems with Applications*, 2010, doi:10.1016/j.eswa.2010.02.095.
21. Kaya, T., Kahraman, C., Multicriteria renewable energy planning using an integrated fuzzy VIKOR & AHP methodology: The case of Istanbul, *Energy*, 2010. doi: 10.1016/j.energy.2010.02.051.
22. S. A. Khaparde and ArunavoMukerjee (2008), 'Infrastructure for Sustainable Renewable Energy in India: A Case Study of Solar PV Installation', *IEEE*, Vol.68, pp. 289-301.
23. Kowalski, K., Stagl, S., Madlener, R., Omann, I., Sustainable energy futures: Methodological Challenges in combining scenarios and participatory multi-criteria analysis, *European Journal of Operational Research*, Vol. 197, No. 3, 2009, pp.1063–1074.
24. Kuo R.J., Chi S.C. and Kao S.S. (2002), 'Decision Support System for Selecting Convenience Store Location through Integration of Fuzzy AHP and Artificial Neural Network', *Computers in Industry*, Vol. 47, pp. 199-214.
25. Lee W.B., Lau H., Liu Z.Z. and Tam S. (2001), 'Fuzzy Analytic Hierarchy Process Approach in Modular Product Design', *Expert Systems*, Vol. 18, pp. 32-42.
26. Liang R.H. (1999), 'Application of Grey Relation Analysis to Hydroelectric Generation Scheduling', *Electric Power and Energy Systems*, Vol. 21, pp.357-364.
27. Lin C.T. and Hsu P.F. (2001), 'Selection of advertising agencies using grey relational analysis and analytic hierarchy process', *Journal of International Marketing and Marketing Research*, Vol. 26, No. 3, pp. 115-128.
28. Madjid Tavana, Francisco J.Santos Arteaga, SomayehMohammadi and Moslem Alimohammadi . (2017), 'A fuzzy multi-criteria spatial decision support system for solar farm location planning', *Energy Strategy Reviews*, Volume 18, 93-105.
29. Öniit, S., Tuzkaya, U. R., Saadet, N., Multiple criteria evaluation of current energy resources for Turkish manufacturing industry, *Energy Conversion and Management*, Vol. 49, No. 6, 2008, pp.1480–1492.
30. R. Nagalakshmi, B. Kishore Babu, D. Prashanth (2014), 'Design and Development of a Remote Monitoring and Maintenance of Solar Plant Supervisory System', *International Journal of Engineering and Computer Science*, Vol. 3 (12), pp. 9382-9385.
31. Patlitizianas, K. D., Pappa, A., Psarras, J., An information decision support system towards the formulation of a modern energy companies' *Environment, Renewable and Sustainable Energy Reviews*, Vol. 12, No. 3, 2008, pp.790–806.
32. T. V. Ramachandra, Rajeev Kumar Jha, S. Vamsee Krishna and B. V. Shruthi (2005), 'Solar energy decision support system', *International Journal of Sustainable Energy*, Vol.24 (4), 207-224.
33. SasikumarGnanasekaran, SelladuraiVelappan and Manimaran P, (2007), An Integrated Model for Supplier Selection Using Fuzzy Analytical Hierarchy Process: A Steel Plant Case Study, *International Journal of Procurement Management*, Vol.3(3), pp. 292–315.
34. Saaty T.L. (1980), 'The Analytic Hierarchy Process', New York: McGraw-Hill.
35. Wang, J. J., Jing, Y. J., Zhang, C. F., Zhao, J. H., Review on multi-criteria decision analysis aid in sustainable energy decision-making, *Renewable and Sustainable Energy Reviews*, Vol. 13, No. 9, 2009, pp.2263-2278.
36. Zavadskas, E. K., Skibniewski, M. J., &Antucheviciene, J. (2014), 'Performance analysis of Civil Engineering Journals based on the Web of Science database', *Archives of Civil and Mechanical Engineering*, Vol.14, pp. 519–527.
37. V. Sharma, S.S. Chandel. (2013), 'Performance analysis of a 190 kWp grid interactive solar photovoltaic power plant in India', *Energy*, 55, pp. 476-485.



38. Wu J.H. and Chen C.B. (1999), 'An alternative form for grey relational grades', *The Journal of Grey System*, Vol. 11 No. 1, pp. 7-12.
39. Wu H.H. (1998), 'A comparative study of using grey relational analysis in multiple attribute decision making problems', *Quality Engineering*, Vol. 15 No. 2, pp. 209-217.
40. Yeh C.H. and Deng H. (1997), 'An Algorithm for Fuzzy Multi-Criteria Decision making', *IEEE International Conference on Intelligent Processing Systems*, Beijing, China.
41. Zhu K.J., Jing Y. and Chang D.Y. (1999), 'Discussion on Extent Analysis Method and Applications of Fuzzy AHP', *European Journal of Operational Research*, Vol. 116, pp. 450-456.

